Occupational Coccidioidomycosis in California

Outbreak Investigation, Respirator Recommendations, and Surveillance Findings

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Objective: To describe the investigation of a 2007 occupational coccidioidomycosis outbreak in California, recommend prevention measures, and assess statewide disease burden. **Methods:** We evaluated the worksite, observed work practices, interviewed the workers and employer, reviewed medical records, provided prevention recommendations including risk-based respirator selection, and analyzed statewide workers' compensation claims. **Results:** Ten of 12 workers developed acute pulmonary coccidioidomycosis; none used respiratory protection. We recommended engineering, work practice, and administrative controls, powered air-purifying respirator use, and medical care. Occupational coccidioidomycosis incidence nearly quadrupled in California from 2000 to 2006, with the highest rates in construction and agricultural workers. **Conclusions:** Construction workers are at risk for occupational coccidioidomycosis. The high attack rate in this outbreak was due to lack of awareness, rainfall patterns, soil disruption, and failure to use appropriate controls. Multiple risk-based measures are needed to control occupational coccidioidomycosis in endemic areas.

Coccidioidomycosis, also known as Valley Fever, is a recognized occupational illness. The Centers for Disease Control and Prevention[1] considers workers engaged in soil-disrupting activities, including military personnel participating in training exercises in endemic areas, to be populations at risk for the disease. Published studies[2–6] have documented occupational disease clusters in endemic areas among military personnel, anthropologists, and archaeologists. Increased disease incidence has been reported among agricultural workers in endemic areas.[7] In nonendemic areas, work-related cases of disease have been reported in various occupations, including laboratory and hospital personnel.[7–11] Coccidioidomycosis may cause disability lasting from days to months.[4]

Coccidioidomycosis is caused by the inhalation of airborne fungal spores from either of the two soil-dwelling *Coccidioides* species: *C. immitis*, native to California, and *C. posadasii*, found outside California. The fungus is endemic to certain semiarid areas of California, Arizona, New Mexico, Nevada, and Texas, and of Central and South Americas.[12] In the United States, the southern San Joaquin Valley and southern Arizona have the highest endemicity.[13] Infection in endemic areas is the result of inhalation of spores following soil disruption. Coccidioidomycosis can be a severe illness and result in disability due to pulmonary involvement and disseminated disease; however, most infections are asymptomatic. Influenza-like illness is the most common clinical presentation. Infection generally imparts immunity to reinfection, although rare cases of reinfection have been reported.[14–17]

State and local health departments involved in investigating previous outbreaks of coccidioidomycosis at endemic sites, and the National Institute for Occupational Safety and Health (NIOSH) guidance document regarding control of airborne fungal infectious agents such as *Histoplasma capsulatum* spores,[2,18] recommend wearing a NIOSH-approved, fit-tested respirator at least as protective as a half-mask respirator with a NIOSH-certified N95 particulate filter when engaged in soil-disturbing activities in endemic areas. Nevertheless, consistent state and federal standards for preventing occupational coccidioidomycosis, including respirator use guidelines, are lacking. Although California's recently enacted Aerosol Transmissible Diseases Standard is the first regulation designed to protect workers from aerosol-transmitted infectious diseases in the workplace, it does not apply to *Coccidioides* outside the laboratory setting.[19]

Despite a considerable volume of literature documenting coccidioidomycosis as an occupational risk, outbreaks continue to occur among workers. In November 2007, the San Luis Obispo County Health Department requested the assistance of the California Department of Public Health (CDPH) in evaluating a suspected cluster of coccidioidal pneumonia in a construction crew at the Camp Roberts military base. This National Guard training site is located on the border of San Luis Obispo and Monterey counties. CDPH jointly investigated the cluster with county staff, evaluated factors that contributed to disease, and made recommendations to prevent future occupational exposures at this worksite. The epidemic curve, descriptive epidemiology, clinical aspects, and laboratory data from this investigation have been described and are consistent with the disease due to a single-point-source exposure that occurred at the Camp Roberts construction site.[20] In this article, we describe the occupational aspects of the investigation, present an analysis of statewide claims for occupational coccidioidomycosis, and discuss recommendations for protection of workers, including risk-based respirator-selection decisions.

METHODS

Worksite Investigation

CDPH industrial hygiene, epidemiology, and medical staff visited the construction site, interviewed workers, and reviewed medical records. During the site visit, staff observed work practices, including personal protective equipment used, and interviewed personnel at the military base. Workers were interviewed over the telephone; the survey instrument utilized for the construction crew included work activities and protective measures used at the outbreak worksite.[20] Demographic characteristics of this crew, medical history, and signs and symptoms have been described.[20] Dust levels were not measured at the excavation site and distance from the trench was deemed to be an unreliable method of determining the risk of dust exposure as workers did not remain in any single location for the duration of their work.

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Workplace Recommendations

CDPH provided worksite-specific health and safety recommendations and initial respiratory protection recommendations to the involved employers and workers. Immediately after the cases were reported, we recommended that the crew use half-mask particulate respirators when digging in soil at Camp Roberts. *C. immitis* spores are approximately 5 μm in diameter[4] and adhere to soil particles of a wide size range, which are effectively captured by NIOSH-certified respirator filters. When the high attack rate for this outbreak became apparent, we revised our recommendations by applying a risk-based approach to respirator selection.

We used a simplified exponential dose–response relationship to estimate the spore dose received by workers at this pipeline construction site.[21] We assumed it takes one spore to result in *C. immitis* infection: Infection risk $= 1 - \exp(-D)$, where D is the expected dose in the alveolar region.[22–24] The dose D is a product of several factors including the spore concentration in ambient air:

$$D = C \times B \times T \times \text{days} \times f$$

C, average spore concentration in air (no./m^3); B, inhalation rate (m^3/hr); T, number of hours per day; days, number of days exposed; f, spore deposition fraction in alveolar region.

Finally, we utilized the Federal Occupational Safety and Health Administration's assigned protection factors (APFs) for respirators to estimate the reduction in infection risk provided by each type of respirator.[25] We assumed that the use of respirators would reduce the average spore concentration (and thereby dose) by a factor determined by the APF.

Workers' Compensation Data

To assess the statewide burden of occupational coccidioidomycosis, we analyzed data from the Workers' Compensation Information System, an electronic administrative claims database maintained by the California Department of Industrial Relations. A surveillance case definition was developed by which a coccidioidomycosis-related claim was identified if the date of injury was between January 2000 and December 2007, and the claim had an *International Classification of Diseases, 9th edition,* code for coccidioidomycosis (114 to 114.5 and 114.9) and/or had an injury description with key words indicating exposure to *C. immitis*. Occupation was coded according to the Census 2000 Index of Occupations.[26] Industry was coded according to the 2002 North American Industry Classification System and organized into 2002 Census Industrial Classifications using a crosswalk produced by the Bureau of Labor Statistics for the Current Population Survey.[27] Claim rates by industry and occupation were calculated for California workers 16 years and older, using estimates of employed civilian population from the 2003 Current Population Survey (midpoint of the time interval examined).[27] The California mining industry population was not listed by Bureau of Labor Statistics due its small labor force base. An estimate was calculated by multiplying the percent of California workers in the mining industry by the total estimate of the California-employed civilian population as reported in the 2003 Current Population Survey.[27] Claim rates were not calculated for industries with less than five claims filed from 2000 to 2007. For rate estimates, 95% confidence intervals were calculated using Byar approximation.[28] All calculations and statistical analysis were conducted using SAS version 9.1 (SAS, Inc, Cary, NC) or Microsoft Excel 2003 (Microsoft, Redmond, WA).

RESULTS

Workplace Investigation

In October 2007, a civilian construction crew excavated a 1200-ft long trench to replace a water pipe at Camp Roberts, a California National Guard military base owned by the US Army in San Luis Obispo County, California. The original pipe, located 20 to 50 ft from the replacement pipe, had failed in January 2006, leaking its full contents across the hillside to the flatlands below.

Ten of the 12 crew members developed clinical symptoms consistent with acute pulmonary coccidioidomycosis (attack rate 83%).[20] Eight had serologically confirmed disease; seven had abnormalities on chest radiograph; and one developed disseminated disease. One worker, without evidence of clinical infection more than 40 days after the outbreak, was diagnosed with coccidioidomycosis in March 2008, following his return to work at the outbreak site in February 2008. The 10 ill crew members sought care from at least 21 physicians and lost a total of at least 1660 hours of work. One worker was assigned to light duty for 160 hours, and two workers were on disability 5 months after the outbreak was detected, the last time the authors had contact with affected crew members.

The 12-member crew worked four 10-hour days per week with some variations over a 10-day period in the East Garrison of Camp Roberts. The crew consisted of two pipe layers, three laborers, three earth-moving equipment operators (using excavator, backhoe, and skid steer), one water truck operator, one dump truck operator, and two supervisors. During interviews, the crew reported that they all worked in the same location, excavating the trench, installing the pipe, packing the excavated soil back around the pipe, and backfilling the trench. The trench (1200-ft long × 4-ft wide × 2- to 5-ft deep) was excavated mechanically and was compacted and backfilled both mechanically and manually. The soil was wetted with water to decrease airborne dust levels and to ensure proper soil compaction around the pipe. When sand was encountered, the crew began intensive wetting using two hoses; however, the sandy soil mostly repelled the water.

Of eight workers who reported their perception of the dust level on the "dustiest" day, two reported low dust, two reported moderate dust, and four reported high dust levels. While the company had access to at least one excavator with air conditioning, the crew was not using that excavator at the time of the outbreak at this location. In addition, the crew always used equipment with the windows open, thus bypassing any dust filtration that the enclosed cab could have provided. Although N95 filtering facepiece respirators were available, workers were not specifically advised by the employer to wear them at this site, and none did so. None of the workers reported having received training on prevention of coccidioidomycosis and before the outbreak, none were aware of a risk of coccidioidal infection at this worksite

The outbreak site was an exposed, west-facing hillside with extensive rodent burrows and where cattle grazed until 6 months before the outbreak. Area rainfall was twice the 30-year average during the winter of 2004-2005, normal in the winter of 2005-2006, and lower than expected in the winter of 2006-2007. The 600,000 gallons of water that leaked from the water tank onto the outbreak site in January 2006 greatly increased the water present at the site during the winter of 2005-2006. In addition, the rains during the winter of 2005-2006 extended into April and May, which was later in the season than usual.

During the course of investigating this outbreak, the San Luis Obispo County Health Department notified CDPH of a military instructor at Camp Roberts who was also confirmed to have coccidioidomycosis on the basis of symptoms, chest radiography, and serologic testing (Figure 1). The instructor was not associated with the construction crew but did work in the same general geographical region; illness was diagnosed during the same time period as those considered part of this outbreak (December 2007).

Workplace Recommendations

CDPH made several recommendations for minimizing exposure and risk of future infection at this construction site (Table 1). These multiple controls were intended to be used simultaneously, On December 19, 2007, a non-smoking Hispanic male National Guard instructor and California resident aged 52 years presented to a military clinic in San Luis Obispo County with a two-week history of headache, fever, cough, shortness of breath, and chest pain and was prescribed Augmentin for presumptive pneumonia. For six months before symptom onset, he had worked on the military base at Camp Roberts training National Guard recruits and preparing terrain for training exercises. His activities included manually removing weeds, digging training holes, and demonstrating maneuvers that involved running or crawling for long distances on the ground without respiratory protection. On January 9, 2008, he presented to an Emergency Department in San Luis Obispo County with worsening symptoms and a 20-pound weight loss. Chest radiography demonstrated consolidation of the right upper lobe and suggested an enlarged right mediastinal lymph node. Coccidioidal serology indicated positive precipitin antibodies and negative complement-fixing antibodies. On January 14, 2008, he was prescribed fluconazole for treatment of coccioidomycosis. Fatigue and dyspnea prevented him from working for six months during which chest radiographs indicated gradual improvement; follow-up serologies were not obtained. He returned to work in July 2008, with residual mild dyspnea on exertion.

FIGURE 1. Clinical details of military instructor diagnosed with coccidioidomycosis at Camp Roberts.

since any single exposure control method would not have been sufficiently protective to minimize exposure and reduce the risk of infection to an acceptable level. These included using high-efficiency particulate air (HEPA) filtered air-conditioned enclosed cabs on heavy equipment and training workers on ways to prevent exposure, such as the proper use of construction equipment, wearing respiratory protection, and controlling dust at the source by continually wetting the soil. Additional recommendations included improving the Injury and Illness Prevention Program, which is mandatory for all California employers, and the medical surveillance program to identify illness prevention strategies, and improve prompt access to medical care for all work-related illnesses and injuries.[29]

Respirator Selection

On the basis of an attack rate for this outbreak of 83%, the expected dose to the alveolar region, D, is calculated as follows:

$$\text{Infection risk} = 1 - \exp(-D)$$
$$0.83 = 1 - \exp(-D)$$
$$\exp(-D) = 0.17$$
$$D = -\ln(0.17) = 1.77 \text{ spore}$$

The risk reduction afforded by two different types of respirators was assessed. The effect of wearing a respirator is to reduce the inhaled concentration, which in turn reduces the expected inhaled dose (D in the risk equation given earlier). Earlier in this article, we showed that the expected dose is a product of the spore concentration in air, the duration of exposure, the volumetric breathing rate of the worker, and the fraction of inhaled spores that deposit in the pulmonary region.

Negative-pressure half-mask air-purifying respirators equipped with N95, N100, or P100 filters have an APF = 10 and would reduce the average spore concentration (C in the equation given earlier) to one tenth of the ambient concentration. Tight-fitting, full-facepiece powered air-purifying respirators (PAPRs) (and some

TABLE 1. Recommendations Provided by California Department of Public Health to San Luis Obispo County Construction Site Employer to Minimize Dust Exposure and Risk of *Coccidioides* Infection

Type of Control	Principle	Components
Engineering and work practices	Control dust at source or isolate worker from exposure	• Continuous soil wetting • Heavy equipment: HEPA-filtered air-conditioned enclosed cabs with 2-way radios • Wash equipment before movement off-site
Administrative	Increase hazard awareness and knowledge of safe work practices	• Train workers and supervisors: ○ Distribution ○ Symptoms and signs ○ Effective controls, including proper use of equipment
	Implement comprehensive illness prevention program	• Injury and Illness Prevention Plan*
Personal protective equipment and hygiene practices	Prevent inhalation exposure	• Respirators when digging or working near earth-moving machinery: ○ Half-mask or full-face respirator with particulate filter† ○ Powered air-purifying respirator with particulate filter‡ ○ Respirator training, fit-testing, and medical clearance • Lockers, coveralls, and change clothing at worksite
Medical care	Disease recognition and prompt, appropriate treatment	• Contract with local medical clinics ○ Protocol for evaluation, follow-up, and treatment ○ Prompt care • Physician training

*California Code of Regulations, Title 8, Section 3203. Injury and Illness Prevention Program. Available at: http://www.dir.ca.gov/Title8/3203.html.

†Initial recommendation made before completion of investigation.

‡Risk-based recommendation based on attack rate in this incident.

helmet/hood PAPRs) with high-efficiency particulate filters have an APF = 1000 and would reduce the average spore concentration to 1/1000 of the ambient air concentration. This information served as the basis for issuing revised recommendations for the appropriate type of respiratory protection in this endemic area. In a similar high-risk worksite, the use of a PAPR (APF = 1000) with HEPA filters would be estimated to reduce the infection risk to 0.17%, whereas a half-mask air-purifying respirator (APF = 10) with HEPA filters would reduce the risk to 16% (Table 2). As a result, we issued an updated recommendation to wear PAPRs (APF = 1000) equipped with HEPA filters when engaging in soil-disrupting activities at this site.

Workers' Compensation Data

During the 8-year period 2000 to 2007, 461 unique coccidioidomycosis claims were identified, and the average annual claim rate was 0.35 per 100,000 workers. Median claimant age was 41 years (range, 18 to 70 years). More than 78% of claimants (n = 360) were male. The largest group of claimants worked in service occupations (n = 133), although the highest claim rates occurred in the occupational categories of farming, fishing, and forestry, and construction and extraction (Table 3). The number and rate of occupational coccidioidomycosis cases nearly quadrupled from 2000 to 2006, but this increase was not sustained in 2007 (Figure 2).

When we categorized workers' compensation data by industry, as opposed to occupation, we obtained slightly different results. From 2000 to 2007, the public administration industry had the highest number of claims due to coccidioidomycosis, whereas the mining, quarrying, and oil and gas extraction industry had far fewer claims but the highest rate (Table 4).

DISCUSSION

The disease outbreak among construction workers described in this article and the analysis of workers' compensation claims data illustrate that, despite known risk factors, occupational coccidioidomycosis remains an important concern in California. The high attack rate at this worksite was most likely a result of general lack of awareness regarding coccidioidomycosis and its endemicity at this site, resulting in inadequate worker training; inability to adequately assess the presence of the organism in soil; rainfall patterns and tank leakage that may have facilitated fungal growth; considerable soil disruption in a geographic area endemic for *C. immitis*; and failure to use appropriate control strategies, including respiratory protection. Recommendations for disease prevention in occupational settings are based on these factors.

TABLE 2. Calculated Risk of Coccidioidal Infection Based on Type of Respirator Used

Respirator Type	Assigned Protection Factor	Infection Risk (%)*
Half-Mask Respirator (elastomeric or filtering facepiece N95)	10	16
Powered Air-Purifying Respirator	1000†	0.17

*Risk of infection at construction site with exposure scenario similar to that described in this article.

†Some powered air-purifying respirators (PAPRs) have an assigned protection factor (APF) of 1000; however, some have a lower APF. The wearer must obtain information from the manufacturer about the APF for each specific PAPR they intend to wear. (California Code of Regulations, Note 4 in Title 8, Section 5144, Respiratory Protection, Table 1—Assigned Protection Factors.)

In 1942, Shelton[30] reported that coccidioidomycosis could be acquired at Camp Roberts, a "hitherto unknown endemic focus." In 2000, the US Geologic Survey[31] still considered this a "suspected endemic region." Nevertheless, in 2007, neither the National Guard, the lessee of this property, nor the employer of the construction

TABLE 3. Number of Cases, Percentage,* and Estimated Average Annual Rate† of Coccidioidomycosis-Related Claims Submitted to the Workers' Compensation Insurance System by Occupation Category, California, 2000 to 2007

Occupation Category (COC)	No. (%)	Rate	95% CI
Farming, fishing, and forestry (600–613)	23 (5)	1.24	0.79–1.87
Construction and extraction (620–699)	78 (17)	1.11	0.88–1.38
Service (360–465)	133 (29)	0.64	0.54–0.76
Production, transportation, and material moving (770–975)	46 (10)	0.30	0.22–0.41
Management, professional, and related (001–354)	100 (22)	0.21	0.17–0.26
Installation, maintenance, and repair (700–769)	7 (2)	0.14	0.05–0.30
Sales and office (470–593)	13 (3)	0.04	0.02–0.06
Unknown	61 (13)	–‡	–‡
Total	461 (100)	0.35	0.32–0.39

*Percentages may not add to 100 because of rounding.
†Per 100,000 civilian workers aged 16 years or older with 95% CI; denominator data from Current Population Survey employed civilian population estimates, 2003.
‡Annual rate and 95% CI could not be calculated because denominator data could not be determined for the category.
CI, confidence interval; COC, 2000 Census Occupation Codes.

crew knew that previous outbreaks had occurred in this region. The diagnosis of coccidioidomycosis in a military instructor at Camp Roberts during the same time period as the outbreak suggests that the risk of the disease was more widespread than at just the construction site and that *Coccidioides* species may have been sporadically present throughout the entire military base.

California regulation requires employers to establish worksite- and hazard-specific Illness and Injury Prevention Plans.[29] Because the endemicity of *Coccidioides* species at Camp Roberts was unrecognized, workers were not provided with training about the risk of disease at this worksite or of work practices to reduce the probability of its occurrence. From 2000 to 2007, surveillance data showed that the rate of coccidioidomycosis in San Luis Obispo County was in the highest quintile of the state, 14.5 to 150.0 cases per 100,000 population.[32] This supports the assertion that *C. immitis* should be considered endemic to this area and that education on the etiology and prevention of the disease should be disseminated to employers, workers, and communities.

Coccidioidomycosis is on the list of National Notifiable Diseases, although not all states have made it reportable.[33] Arizona and California are among the states where coccidioidomycosis is a reportable condition. From 1997 to 2007, the incidence rate increased 281% in Arizona.[13] In California, the numbers of cases and the incidence rate more than tripled from 2000 to 2006.[32] Reported coccidioidomycosis cases in California increased from 816 in 2000 (incidence rate, 2.4 per 100,000 population) to 2981 in 2006 (8.0 per 100,000 population). Postulated factors accounting for rising disease incidence include climate change; migration patterns, including movement of susceptible populations to endemic areas; and new construction in endemic areas.[13,34]

Our finding of the near quadrupling of coccidioidomycosis incidence in California workers' compensation claims from 2000 to 2006 reflects trends in the general population and among military personnel in California for the same time period.[5,32] The significance of the decreased incidence in 2007, in both the general population and among workers, is unknown at this time. The highest rates of coccidioidomycosis were observed among agricultural and construction workers, who are likely to have the greatest dust exposure, and in the mining industry, which involves considerable soil disruption. The high numbers of cases observed in public administration may have been due to the inclusion of the public safety industry, which in California has experienced several recent large outbreaks of coccidioidomycosis in prisons.[35–37] The distribution of coccidioidomycosis among occupational groups is consistent with historical reports of the highest disease rates among construction and agricultural workers in California.[4]

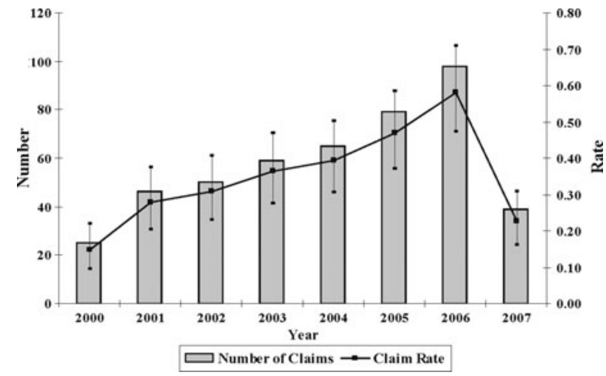

FIGURE 2. Number and estimated rate* of coccidioidomycosis-related workers' compensation claims† by year, California, 2000 to 2007 ($n = 461$). *Per 100,000 civilian workers aged 16 years or older with 95% confidence interval; denominator data from the Current Population Survey employed civilian population estimates. †Data are derived from our analysis of the Workers' Compensation Information System, an electronic administrative claims database maintained by the California Department of Industrial Relations.

Although the overall pattern of coccidioidomycosis incidence obtained from our analysis of workers' compensation claims reflects population trends, both the overall numbers and the rates among workers are much lower than those in the general population for the same time period. This is most likely because the disease is not recognized as work-related except in outbreak situations; it is also possible that work-related coccidioidomycosis is underreported by workers and/or physicians, or that occupational exposure accounts for a small proportion of cases.

Our examination of workers' compensation data showed that occupational incidence rates decreased in 2007, the year this outbreak occurred. Local issues and weather patterns may have played a role in this outbreak. *C. immitis* thrives during wet periods after droughts, and disease incidence is correlated with rainfall in recent previous seasons.[38,39] Heavy rainfall 2 years before this outbreak and leakage of the water tank at the site during the previous winter may have contributed to fungal growth. Interestingly, Zender and Talamantes[40] found that precipitation and other weather patterns (such as wind) explain a much smaller proportion of coccidioidomycosis incidence in California (4%) compared with Arizona (75%). These authors have therefore suggested that human soil-disrupting activity, such as digging in endemic areas, is the most important determinant of coccidioidomycosis incidence in California. Nevertheless, soil sampling is unreliable for predicting the presence of *C. immitis* spores. Even in endemic areas, spores are unevenly distributed, and false-negative results may lead to an inappropriate

TABLE 4. Number of Cases, Percentage,* and Estimated Average Annual Rate† of Coccidioidomycosis-Related Claims Submitted to the Workers' Compensation Insurance System by Industry Category, California, 2000 to 2007

Industry Category (CIC/NAICS)	No. (%)	Rate	95% CI
Mining, quarrying, and oil and gas extraction (0370-0490/ 21)	9 (2)	6.91	3.15–13.12
Public administration (9370-9590/ 92)	181 (39)	3.07	2.64–3.56
Agriculture, Forestry, Fishing, and Hunting (0170-0290/ 11)	25 (5)	1.00	0.65–1.48
Construction (0770/ 23)	67 (15)	0.75	0.58–0.95
Transportation and utilities (0570-0690, 6070-6390/ 22, 48-49)	26 (6)	0.45	0.29–0.65
Professional and business services (7270-7490, 7570-7790/ 54, 55-56)	31 (7)	0.20	0.13–0.28
Education and health services (7860-8470/ 61-62)	45 (10)	0.18	0.13–0.24
Manufacturing (1070-3990/ 31-33)	14 (3)	0.09	0.05–0.15
Other industries‡	13 (3)	–§	–§
Unknown	50 (11)	–§	–§
Total	461 (100)	0.35	0.32–0.39

*Percentages may not add to 100 because of rounding.
†Per 100,000 civilian workers aged 16 years or older with 95% CI; denominator data from Current Population Survey employed experienced civilian population estimates, 2003.
‡All major CIC industry categories had claims, but major industries with less than five claims were excluded from rate analysis.
§Annual rate and 95% CI could not be calculated because denominator data could not be determined for the category.
CI, confidence interval; CIC, 2002 Census Industrial Classification; NAICS, 2002 North American Industry Classification System.

sense of security. Moreover, the assay method is expensive, time-consuming, and not available commercially.[3,12,41,42]

The excavation and replacement of the damaged water line at this National Guard training site involved considerable soil disruption. The crew's attempts to control dust through wetting were inadequate because the sandy soil failed to absorb water. Occupational risk factors, such as job title and duties, were not associated with disease risk or severity.[20]

In spite of the inability to quantify exposure, the high attack rate reflects that workers had a sufficient dose of *C. immitis* spores over the course of their work at the site to cause clinical illness. Similarly, high attack rates have been reported in previous occupational outbreaks involving soil-disrupting activities.[43–45] The high attack rate is in part due to several properties exhibited by *C. immitis* spores: easy dispersion, respirability, and infectivity. Spores are 2 to 5 μm in diameter and are able to reach terminal bronchioles and alveoli.[4,46] In animals, 10 spores are sufficient to cause infection.[46] It has been suggested that human illness could be caused by a single spore.[22]

The high attack rate and low human infectious dose were important considerations in developing respiratory protection recommendations for this worksite. Use of PAPRs with an APF of 1000 and HEPA filters would reduce the calculated risk of infection to 0.17%; half-mask respirators equipped with filters would result in an unacceptably high risk of 16%. Since the pattern of distribution of *C. immitis* is unpredictable, it is prudent to expect that spores may be present in soil throughout the Camp Roberts site. Consequently, CDPH recommended workers at Camp Roberts (including military personnel) wear PAPRs with HEPA filters anywhere on the site when manually digging in soil or working in dusty conditions unless in an enclosed cab with HEPA air filtration.

A PAPR, available with a loose-fitting hood, helmet, or tight-fitting, full facepiece, also provides eye protection in dusty work and is more comfortable than half-mask respirators for breathing, communication, and temperature and humidity inside the facepiece. These features might increase worker compliance with respirator use in dusty construction settings.[47] Nevertheless, since personal protective equipment is the least effective measure in reducing exposure to hazards, and since there are many potential barriers to respirator use in construction, CDPH recommended that a respiratory protection program at this worksite be part of a multifaceted approach to reducing the risk of coccidioidomycosis.[48] These include engineering, work practice, administrative controls, and medical care (Table 1).

Engineering and work practice controls consist of dust-suppression measures during construction in endemic areas: continuous soil wetting, avoiding outdoor construction during unusually windy conditions, and using enclosed heavy equipment cabs with HEPA filtered air-conditioning.[4,31] During the incident at Camp Roberts, soil wetting was attempted but was ineffective in controlling dust, demonstrating that any single measure may be inadequate to control exposure to *Coccidioides* spores. Because occupational coccidioidomycosis has been attributed to airborne exposure to spores contained in resuspended dust, equipment and vehicles should be cleaned before transport off-site, and clothing and shoes should be removed before leaving the worksite.[3] Administrative controls include development and adherence to an injury and illness prevention program that acknowledges hazards and implements mitigation methods, including provision of worker and employer training. When working in endemic areas, workforces should receive annual training about coccidioidomycosis symptoms, high-risk activities, dust-control methods, and respiratory protection. Finally, ensuring prompt access to medical care is essential. Because of the public health impact of coccidioidomycosis and because local health care providers vary in their knowledge of this disease, public health authorities should support programs to educate providers on its recognition, diagnosis, management, and prevention in workers. To date, therapeutic options remain limited and, despite considerable research, a preventive vaccine is not available.[49] Health care providers in endemic areas should consider coccidioidomycosis in the differential diagnosis of influenza-like symptoms, particularly in persons with soil-disturbing occupations or persons who have moved or traveled to endemic areas.

There are several historical recommendations for reducing the risk of infection due to *C. immitis* spores during soil-disrupting activities, including spraying the ground with oil.[4,50] But there is insufficient evidence demonstrating that this latter method is effective; moreover, potential adverse effects on human health and the environment are unknown. Skin testing has also been proposed as a method to allow only workers with evidence of previous infection access to endemic areas.[4] Nevertheless, there is currently no commercially available skin test for past coccidioidal infection. Finally, restricting the work force to "resident labor" has been recommended as a screening method to reduce occupational infection. This proposal was based on the presumption that residents of endemic areas were more likely to have had subclinical infection and therefore be immune to reinfection. In the outbreak described in this article, many workers were from endemic areas, but nonetheless developed coccidioidomycosis, suggesting that workers from endemic areas are not necessarily immune and remain at risk for being infected.[20]

Occupational coccidioidomycosis remains an important concern in some parts of the United States. Infection risk is highest in workers engaging in soil-disrupting activities such as construction and agriculture. A multitude of controls should be utilized to reduce exposure to dust-containing spores of soil-dwelling *Coccidioides* species. In addition to engineering, work practice, and administrative controls, quantitative risk-based calculations provide a framework for making informed decisions for selecting respiratory protection. We have used these calculations to demonstrate that the use of PAPRs (APF = 1000) with HEPA filters at the site of this outbreak would likely reduce the infection risk to a level that is more acceptable than that associated with half-mask elastomeric or filtering facepiece respirators with N95, N100, or P100 filters. Occupational coccidioidomycosis may be better controlled in endemic areas by implementing the multifaceted measures described in this article.

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